1.1.1.1.1.5 Chapter

6

6. High Altitude and Terrain Considerations

6.1 Measurement of atmospheric pressure

A barometer is generally used to measure the height of a column of mercury in a glass tube. It is sealed at one end and calibrated in inches. An increase in pressure forces the mercury higher in the tube; a decrease allows some of the mercury to drain out, reducing the height of the column. In this way, changes of pressure are registered in inches of mercury. The standard sea-level pressure expressed in these terms is 29.92 inches at a standard temperature of 15 degrees C. (59 degrees F.).

The mercury barometer is cumbersome to move and difficult to read. A more compact, easily read and mobile barometer is the aneroid, although it is not as accurate as the mercurial. The aneroid barometer is a partially evacuated cell that is sensitive to pressure changes. The cell is linked to an indicator that moves across a scale that is graduated in pressure units. A common aneroid barometer is the altimeter.

If all weather stations were at sea level, the barometer readings would give a correct record of the distribution of atmospheric pressure at a common level. To achieve a common level, each station translates its barometer reading into terms of mean sea level (MSL) pressure. A change of 1,000 feet of elevation makes a change of about 1 inch on the barometer reading. Thus, if a station located 5,000 feet above sea level found the mercury to be 25 inches high in the barometer tube, it would translate and report this reading as 30 inches.

Since the rate of decrease in atmospheric pressure is fairly constant in the lower layers of the atmosphere, the approximate altitude can be determined by finding the difference between pressure at sea level and pressure at the given atmospheric level. In fact, the aircraft altimeter is an aneroid barometer with its scale in units of altitude instead of pressure.

It can be concluded that atmospheric pressure decreases as altitude increases. It can also be stated that pressure at a given point is a measure of the weight of the column of air above that point. As altitude increases, pressure diminishes as the weight of the air column decreases. This decrease in pressure (increase in density altitude) has a pronounced effect on flight.

6.2 Aircraft performance limitations

The air in which all aircraft operate is a dynamic and constantly changing environment. Changes within the air mass can have a profound effect on performance of aircraft engines, wings, propellers, and the individuals who operate aircraft. If all missions were conducted on cool, low humidity days in South Florida or along the Gulf coast, there would be no concern with air density and its implications on flight safety. Obviously, this isn't the case. In fact, these conditions have often been primary factors in aircraft accidents, and may result in loss of the search aircraft unless you pay careful attention. This section will cover the forces at work and identify strategies for dealing with them.

The average pressure exerted by the atmosphere is approximately 15 pounds per square inch at sea level. This means that a column of air 1 inch square extending from sea level to the top of the atmosphere would weigh about 15 pounds. However, the actual pressure at a given place and time depends upon several factors, including altitude, temperature, and density of the air. These conditions very definitely affect flight.

The most noticeable effect of the decrease in pressure (increase in density altitude) due to an altitude increase becomes evident in takeoffs, rates of climb, and landings. An airplane that requires a 1,000-foot run for takeoff at a sea-level airport will require a run almost twice as long to take off at an airport which is 5,000 feet above sea level.

The purpose of the takeoff run is to gain enough speed to generate lift from the passage of air over the wings. If the air is thin, more speed is required to obtain enough lift for takeoff -- hence a longer ground run. It is also true that the engine is less efficient in thin air, and the thrust of the propeller is less effective. The rate of climb is also slower at the higher elevation, requiring a greater distance to gain the altitude to clear any obstructions. In landing, the difference is not so noticeable except that the plane has greater groundspeed when it touches the ground.

Three factors affect the density of the air mass: humidity, temperature, and altitude. Humidity has a smaller effect on air density and aircraft performance than temperature or altitude, and it's nearly impossible to precisely identify the effect. Most engine and airplane manufacturers don't provide performance figures or test data to help the crew determine the effect of humidity on aircraft performance. Nevertheless, observers are expected to have an understanding of the effect humidity has on air density.

6.2.1 Humidity

The air mass is a blend of gases including oxygen, carbon dioxide, nitrogen (the most plentiful), gaseous water or water vapor, and other trace gases. A molecule of gaseous water *weighs* only 64% of the weight of a molecule of free nitrogen. As humidity increases (or more molecules of water vapor are present), molecules of nitrogen and other gases are displaced. Humid air weighs <u>less</u> than an equivalent amount of dry air.

Because the humid blend of gases is less dense, propellers and tail rotors generate less thrust. Wings, main rotors, and control surfaces develop less lift. Further, because oxygen molecules have been displaced, fewer molecules are available for fuel mixing. Engines don't develop as much power as they might in dryer air.

6.2.2 Temperature

The temperature of the air has a greater effect on air density than humidity. As the temperature of any unconfined gas increases, its molecules move farther apart. The gas now weighs less than the same volume of gas at a cooler temperature. The effects of this loss of air density are the same as the effects of humidity. Unlike humidity, these effects are easily determined by the pilot by using the operating handbook.

Air Temperature °F	Horsepower	Landing Distance
34	113	1295 feet
52	110	1330 feet
70	107	1360 feet
88	104	1390 feet

Compiled from aircraft flight manual. Presented here for training purposes only.

Figure 6-1

As shown in Figure 6-1, a light aircraft engine operating at a constant altitude and constant power setting *loses* 3 horsepower for each 18-degree increase in air temperature. The same plane's required landing distance *increases* by about 30 feet for each 18-degree increase. Performance loss by other manufacturers' engines and airplanes will of course vary from those presented here, but the effect is the same.

6.2.3 Altitude

Altitude can be expressed in terms of the airplane's height above ground level (AGL) or its height above mean sea level (MSL). This section will cover altitude in terms of the plane's height above sea level, the *sum* of the airplane's height above the terrain *plus* the terrain elevation above sea level.

Elevation	Temperature	Engine Horsepower	Rate of Climb	Take Off Distance
Sea Level	59°F	160	700 feet/minute	1,627 feet
	85°F	-	-	1,810 feet
7,000'	59°F	140	338 feet/ minute	3,627 feet
	85°F	-	-	4,200 feet

Compiled from aircraft flight manual. Presented here for training purposes only.

Figure 6-2

Unlike water, which cannot be compressed under pressure, the gases in the atmosphere *can* be compressed by pressure. Thus, the molecules are more dense near the earth's surface. At sea level, air pushes downward and laterally with an approximate force of 14.7 pounds per square inch. The higher one goes above sea level, the less the pressure pushing downward. This decrease in density that occurs as altitude increases has the same effect on aircraft and engine performance as humidity and heat, but of significantly *greater* magnitude.

As another example, at an airport near sea level like Key West, Florida, an aircraft engine develops 160 horsepower at maximum power. The same engine at Durango, Colorado, (elevation 6,685 feet above sea level) only develops approximately 140 horsepower at maximum power. The plane's rate of climb is cut by *one half*, and at maximum takeoff weight the distance required for takeoff is *doubled* -- due only to the difference in air densities at the two elevations. This additional loss of performance is shown in Figure 6-2.

The <u>combined</u> effects of temperature and altitude may be very significant. By adding the search altitude to the terrain elevation of the area to be searched, you can determine the altitude above sea level at which you will fly the mission. Then, figure the *density altitude* by applying temperature to that altitude. Figure 6-3, a density altitude table, is one means the crew may use to determine density altitude.

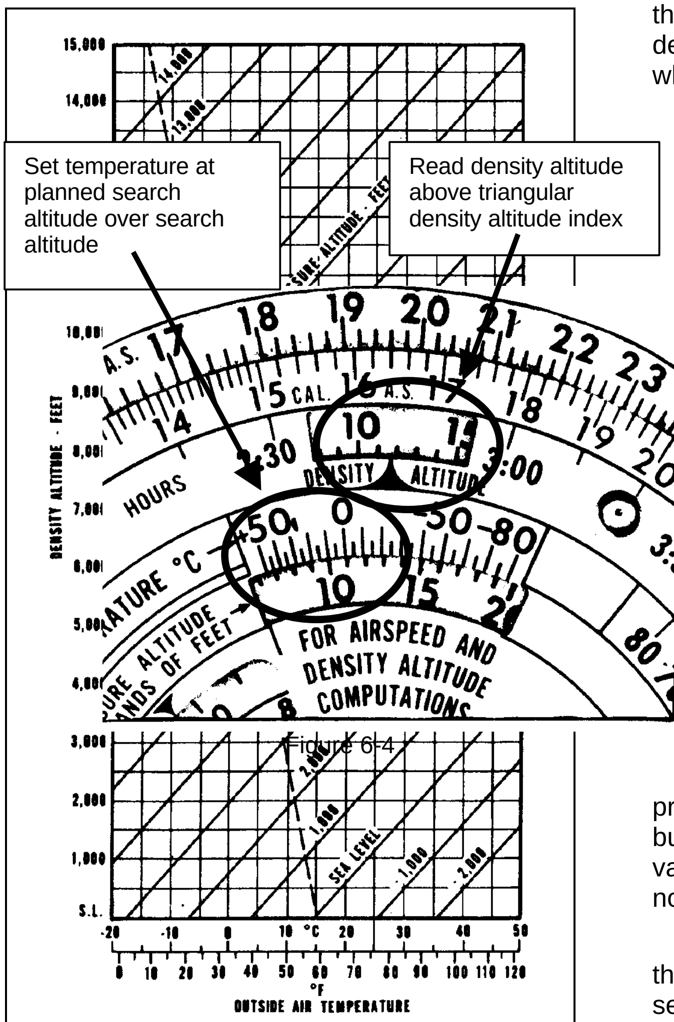

Figure 6-4

Figure 6-3

It's important to understand that density altitude helps the pilot determine the expected loss of engine and airplane performance from higher altitude and temperature. It's *not* a number you will actually read on the aircraft altimeter. As indicated earlier, humidity is not considered in this determination.

Use density altitude and the operating handbook to determine takeoff, climb, and landing performance. Each airplane manufacturer has data that is specific to each type and model of airplane. The data is usually presented in easy-to-use tables or graphs, but the various manufacturers use a variety of methods. Specific methods will not be addressed in this text.

The preceding sections have covered the affects of temperature and altitude separately. However, these factors don't occur separately, and the affects of increased temperature *and* altitude are very important. From the previous example, the Key West engine develops 160 horsepower and the aircraft requires a 1,627-foot takeoff distance on a 59° day. As air temperature increases to 85° that takeoff distance increases to 1,810 feet. The Durango engine develops 140 horsepower and requires 3,627 feet for take-off at 59°. As the Durango temperature increases to 85° takeoff distance increases to over 4,200 feet. It's still the same airplane, same engine, and same weight, only the effects of high air temperature and high elevation are becoming critical. Imagine the "impact" of these factors if the Durango runway were only 3,800 feet long!

Away from the airport, the effect of high-density altitude still has a great affect on aircraft performance. The manufacturer of each CAP-operated airplane has published in the operating handbook a “service ceiling” for that airplane. The service ceiling is that altitude at which the airplane can no longer maintain at least a 100-foot per minute climb rate. For many CAP single-engine airplanes, having engines that are neither super-charged nor turbo-charged, this ceiling is near 13,000 feet. While searches would not normally be conducted at such an altitude, the effect of temperature and air density can bring the service ceiling *down*, and it may become a factor at altitudes commonly used by CAP aircraft.

Imagine a hypothetical July search based at Truth or Consequences, New Mexico, where the airport elevation is 4,850 feet above sea level. Air temperature is reported at 84°F or 29°C. The terrain in the search area rises about 3,000 feet above the airport, and the assigned search altitude is 1,000 feet above the terrain. The altitude you would expect to read on the airplane’s altimeter could be determined as follows:

4,850 feet - airport elevation above sea level

+3,000 feet - height of terrain to be searched

+1,000 feet - search altitude

8,850 feet - search altitude above sea level

You can use either a density altitude table (like the one in Figure 6-4) or the slide rule “face” of the whiz wheel to determine the density altitude. Because air temperature decreases about 2°C for each 1,000 feet of altitude, air temperature at 9,000 feet will be about 21°C. Enter the table at the bottom at 21°C, and move up until you intersect the 9,000 foot search altitude diagonal line. Then look across to the left and find the density altitude of about 11,500 feet.

On the flight computer, set +21° on the temperature scale in the temperature/altitude “window” over the 9,000-foot search altitude, as shown in Figure 6-4. Read the density altitude above the triangular density-altitude index mark.

Again, the density altitude is about 11,500 feet. This is very close to the density altitude-equivalent service ceiling. The climb rate will likely be only slightly better than 100 feet per minute.

A climb rate of 100 feet per minute at 120 knots gives a no-wind climb angle or gradient of approximately 50 feet per mile, <u>substantially less</u> than that required to climb over rapidly rising, mountainous terrain.

Compared to turns at low altitude, turns in high-density altitudes have larger turn radiuses and slower turn rates. The airplane cannot reverse course so quickly and a 180° turn requires more room. Steep-banked, tight turns should also be avoided because the aircraft may have insufficient power or speed (or both) to complete the turn without losing altitude.

Crews must be constantly careful that the search never takes them over terrain that rises faster than the airplane can climb. Narrow valleys or canyons that have rising floors must be avoided, unless the aircraft can be flown from the end of higher elevation to the lower end, or the pilot is *certain* that the aircraft can climb faster than the terrain rises. Careful chart study by the crew prior to flight will help identify this dangerous terrain.

Density altitude’s effect on twin-engine aircraft can be catastrophic in the event of a power loss by one engine. Most CAP-operated “twins” would not be able to climb at all and may not be able to maintain level flight under such circumstances. The pilot then flies an airspeed that allows a minimum rate of descent and starts looking for a suitable place to land. Hopefully, a runway will be nearby.

6.2.4 Strategies

The search and rescue team can make a number of decisions that can help minimize effects of high density altitude and maximize flight safety. If aircraft having turbo-charged or super-charged engines are available, the incident commander may assign their crews that part of the search over the high terrain. Supercharging or turbocharging regains some of the engine performance lost with the decrease in air density, but cannot improve upon that lost from the wings or propeller. If no supercharged or turbo-charged aircraft are available, then the ones with the larger engines should be assigned to search the high terrain (e.g., C-182 instead of a C-172).

Incident commanders may schedule flights to avoid searching areas of high elevation during the hottest times of the day. This is a tradeoff though, in that the best sun angles for good search visibility often coincide with the hot times of the day. The IC/MC may also elect to limit crew size to minimize airplane total weight. Instead of dispatching a four-seat aircraft with a pilot, observer, and two scanners aboard, she may elect to send a pilot, observer and single scanner only. Again, this represents a tradeoff, where some search capability is sacrificed for a higher margin of safety.

The pilot may decide to takeoff on a mission with only the fuel required for that mission and the required reserve, rather than departing with full fuel tanks. Each crewmember can help by leaving all *nonessential* equipment or personal possessions behind. In high density altitudes, airplane performance can be improved significantly by simply leaving nonessential, excess weight behind.

To help remember these conditions and their effects, an observer should remember the four H's: Higher Humidity, Heat, or Height all result in reduced aircraft performance. Available engine power is reduced, climb capability is reduced, and takeoff and landing distances are increased.

6.3 Effects on crewmember performance

The factors previously discussed can have similarly degrading effects on the ability of crewmembers to perform their job tasks. As air temperature increases, so does each crewmember's susceptibility to nausea, airsickness, and dehydration. As humidity increases with temperature, the body's ability to regulate its own temperature by perspiration can be negatively affected, beginning the initial symptoms of heat exhaustion.

When operating in high temperatures, crewmembers should dress accordingly and make every effort to drink plenty of water, juice, or caffeine-free soft drinks prior to, during, and after each mission to help prevent dehydration.

Heat related problems can be mitigated by increasing the flow of outside air through the aircraft interior. If sufficient airflow cannot be gained, cooler air can usually be located by climbing the aircraft to a higher altitude; however, this may be inconsistent with assigned search altitudes or beyond the performance capability of the aircraft.

Altitude has several affects on human performance including ear block, sinus block and hypoxia. Observers should be aware of these factors in their own performance and also watch for them to occur in other crewmembers.

6.3.1 Ear block

As aircraft cabin pressure decreases during ascent, the expanding air in the middle ear pushes the eustachian tube open and, by escaping down to the nasal passages, equalizes with the cabin pressure. However, during descent the crewmembers must periodically open the eustachian tube to equalize pressure. This can be accomplished by swallowing, yawning, tensing muscles in the throat or, if these do not work, by the combination of closing the mouth, pinching the nose closed and attempting to blow through the nostrils (valsalva maneuver).

Either an upper respiratory infection, such as a cold or sore throat, or a nasal allergic condition can produce enough congestion around the eustachian tube to make equalization difficult. Consequently, the difference in pressure between the middle ear and aircraft cabin can build up to a level that will hold the eustachian tube closed, making equalization difficult if not impossible. This problem is commonly referred to as an "ear block."

An ear block produces severe ear pain and loss of hearing that can last from several hours to several days. Rupture of the eardrum can occur in flight or after landing. Fluid can accumulate in the middle ear and become infected. An ear block is prevented by not flying with an upper respiratory infection or nasal allergic condition. Adequate protection is usually not provided by decongestant sprays or drops to reduce congestion around the eustachian tube. Oral decongestants have side effects that can significantly impair pilot performance. If an ear block does not clear shortly after landing, a physician should be consulted.

6.3.2 Sinus block

During ascent and descent, air pressure in the sinuses equalizes with the aircraft cabin pressure through small openings that connect the sinuses to the nasal passages. Either an upper respiratory infection or a nasal allergic condition can produce enough congestion around the openings to slow equalization and, as the difference in pressure between the sinus and cabin increases, eventually plug the opening. This "sinus block" occurs most frequently during descent.

A sinus block can occur in the frontal sinuses, located above each eyebrow, or in the maxillary sinuses, located in each upper cheek. It will usually produce excruciating pain over the sinus area. A maxillary sinus block can also make the upper teeth ache. Bloody mucus may discharge from the nasal passages.

A sinus block is prevented by not flying with an upper respiratory infection or nasal allergic condition. Adequate protection is usually not provided by decongestant sprays or drops to reduce congestion around the sinus openings. Oral decongestants have side effects that can impair pilot performance. If a sinus block does not clear shortly after landing, a physician should be consulted.

6.3.3 Hypoxia

Hypoxia is a state of oxygen deficiency in the body sufficient to impair functions of the brain and other organs. Hypoxia from exposure to altitude is due only to the reduced barometric pressures encountered at altitude, as the concentration of oxygen in the atmosphere remains about 21 percent from the ground up to space.

Although deterioration in night vision occurs at a cabin pressure altitudes as low as 5,000 feet, other significant effects of altitude hypoxia usually do not occur in the normal healthy pilot below 12,000 feet. From 12,000 to 15,000 feet of altitude, judgment, memory, alertness, coordination and ability to make calculations are impaired, and headache, drowsiness, dizziness and either a sense of well being (euphoria) or belligerence may occur. In fact, pilot performance can seriously deteriorate within 15 minutes at 15,000 feet.

At cabin pressure altitudes above 15,000 feet, the periphery of the visual field grays out to a point where only central vision remains (tunnel vision). A blue coloration (cyanosis) of the fingernails and lips develops. The ability to take corrective and protective action is lost in 20 to 30 minutes at 18,000 feet and 5 to 12 minutes at 20,000 feet, followed soon thereafter by unconsciousness.

The altitude at which significant effects of hypoxia occur can be lowered by a number of factors. Carbon monoxide, inhaled in smoking or from exhaust fumes, lowers hemoglobin (anemia). Certain medications can reduce the oxygen-carrying capacity of the blood to the degree that the amount of oxygen provided to body tissues will already be equivalent to the oxygen provided to the tissues when exposed to a cabin pressure altitude of several thousand feet. Small amounts of alcohol and low doses of certain drugs, such as antihistamines, tranquilizers, sedatives and analgesics can, through their depressant actions, render the brain much more susceptible to hypoxia. Extreme heat and cold, fever and anxiety increase the body's demand for oxygen, and hence its susceptibility to hypoxia.

Hypoxia is prevented by avoiding factors that reduce tolerance to altitude, by enriching the inspired air with oxygen from an appropriate oxygen system and by maintaining a comfortable, safe cabin pressure altitude. For optimum protection, pilots are encouraged to use supplemental oxygen above 10,000 feet during the day and above 5,000 at night. The Federal Aviation Regulations require that the minimum flight crew be provided with and use supplemental oxygen after 30 minutes of exposure to cabin pressure altitudes between 12,500 and 14,000 feet, and immediately on exposure to cabin pressure altitudes above 14,000 feet. Every occupant of the aircraft must be provided with supplement oxygen at cabin pressure altitudes above 15,000 feet.

6.4 Mountainous terrain

When flying in mountainous areas it is recommended that flights be planned for early morning or late afternoon, because heavy turbulence is often encountered in the afternoon, especially during summer. In addition, flying during the coolest part of the day reduces density altitude. Attempt to fly with as little weight as possible, but don't sacrifice fuel; in the event of adverse weather, the additional reserve could be a lifesaver.

Study sectionals for altitudes required over the route and for obvious checkpoints. Prominent peaks make excellent checkpoints, but rivers and passes also make good checkpoints. Be aware that mountain ranges have many peaks, some of which may look the same to the untrained eye; continually crosscheck your position with other landmarks and radio aids if possible. Also, the minimum altitude at which many radio aids are usable is higher in the mountains. For this reason low-frequency navigation, such as ADF, LORAN, or GPS, tend to work best in the mountains.

A weather check is essential for mountain flying. Ask specifically about winds aloft even when the weather is good. Expect winds above 10,000 feet to be westerlies in the mountain states. If winds aloft at your proposed altitude are above 30 knots, do not fly. Winds will be of much greater velocity in passes, and it will be more turbulent as well. Do not fly closer than necessary to terrain such as cliffs or rugged areas. Dangerous turbulence can be expected, especially when there are high winds.